THE WORLD BANK

POVERTY REDUCTION AND ECONOMIC MANAGEMENT NETWORK (PREM)

Economic Premise

JUNE 2014 • Number 145

Public Research Organizations and Agricultural Development in Brazil: How Did Embrapa Get It Right?

Paulo Correa and Cristiane Schmidt

One of the most extraordinary events in Brazil in the past 30 years has been the country's "agricultural revolution." In the 1970s, food scarcity was a concrete risk in a country experiencing rapid urbanization and middle class expansion. Food scarcity concerns reemerged during the following decade when short-lived spikes in real wages temporarily increased households' demand for those goods. One of the government's initiatives to address Brazil's stagnant agriculture sector and food scarcity was Embrapa (Empresa Brasileira de Pesquisa Agropecuária). Embrapa has succeeded in adapting, creating, and transferring technologies to Brazilian farmers for the past 30 years, helping transform Brazil into one of the world's largest food exporters. How did Embrapa get it right when similar organizations failed?

Embrapa was created in 1973 as an agricultural research organization under Brazil's Ministry of Agriculture and was almost entirely funded by government resources. Pursuing a clear vision of recuperating and boosting the agricultural sector, Embrapa has developed and transferred more than 9,000 technologies to Brazilian farmers. Researchers working at Embrapa have created over 350 cultivars[1] and obtained more than 200 international patents. Embrapa's key contributions to agricultural development include:

- "Agricultural liming" techniques that turned the acidic soil of the Brazilian *Cerrado* into arable land by neutralizing the soil's pH levels; the transformation of the Cerrado—a biome covering about 22 percent of Brazil's surface area—kept the price of marginal land low and the expansion of agriculture at internationally competitive prices possible.
- Cross-breeding techniques that led to the development of soybean varieties more tolerant to the Cerrado's acidic soils and with a lifecycle up to 12 weeks shorter than that of the typical plant, enabling two harvests per year.
- The development of cottonseeds adapted to the semihumid tropical conditions made it possible to obtain much higher yields per hectare (which tripled between 1983 and 2010) and a fiber quality equivalent to that of the imported product. This represented an important turnaround for this sector that employed large contingents of unskilled labor and had suffered from low productivity, plant disease, and international competition.

By the late 2000s, the Brazilian agricultural sector not only met the country's consumption needs amid robust poverty reduction, it was also leading global markets in agriculture goods and livestock (such as coffee, sugar, orange juice, beef, and poultry). According to some researchers, agriculture development in Brazil also had large impacts in terms of social inclusion (Bonelli 2002).

The modernization of Brazilian agriculture resulted from the convergence of many factors. For example, efficient producers in the Cerrado tend to be large farms that can seize scale economies and are well integrated, vertically and horizontally, in the market.[2] *Well-functioning markets* for arable land enabled the emergence of large agricultural units and the achievement of economies of scale at production level. Trade liberalization—which substantially reduced the prices of agricultural inputs (herbicides, pesticides, insecticides, fertilizers, tractors, and others) is another factor contributing to the sector's rapid modernization. Created as part of the government response to food scarcity and growing macroeconomic imbalances due to growing imports of agricultural goods, the Brazilian agricultural research company Embrapa is arguably a major factor contributing to the systematic increases in Brazil's agricultural productivity. [3]

Agricultural productivity gains in Brazil in the 1980s and 1990s were closely related to improved tropical agriculture knowledge and its effective use by local farmers. Embrapa's new technologies built on these developments in at least two ways: first, they enabled the expansion of agriculture and cattle ranching activities into Brazil's Cerrado, one of the largest reserves of arable land in the world. This process helped keep the cost of the marginal land down and the growth of Brazilian agricultural production internationally competitive. Second, the development of seeds that were more suitable for tropical climate conditions (and the Cerrado's soil) helped increase land productivity for a number of crops, especially those originally grown in temperate climate regions.

Embrapa's successful experience is at odds with the performances of many other public research institutes in developing countries, which often struggle to generate high-quality research and effectively transfer technology to farmers. It is also at odds with the expected performance of organizations that share Embrapa's general governance structure: a publicly owned company under the Ministry of Agriculture and essentially funded by public resources. In most cases, this governance structure ensures failure. Why did Embrapa succeed where other research organizations failed? Is its experience replicable?

Briefly, this note argues that Embrapa's success is due to four main factors:

(i) *Adequate levels of public funding.* Embrapa's expenditures in the last 20 years, at around 1 percent of Brazil's agricultural gross domestic product (GDP), compare well with figures of public spending on agricultural research and development (R&D) in more developed countries, such as Canada, the United States, and Australia (1.2, 1.4, and 0.8 percent, respectively, for 2006–9).

(ii) *Sustained investment in human capital.* Twenty percent of Embrapa's budget was invested in the education and training of its employees between 1974 and 1982 alone. Currently, three-fourths of Embrapa's 2,000 researchers hold a PhD.

(iii) *International collaboration and research excellence.* From the beginning, researchers were drawn from leading universities, setting a high standard of research excellence. Furthermore, Embrapa strengthened its international links by establishing "virtual labs abroad" on three continents to institutionalize knowledge generation and exchange.

(iv) *A mission orientation and IPR policy*. Embrapa was created with "the mission to provide feasible solutions for the development of Brazilian agribusiness through knowledge and technology generation and transfer." Curiosity-driven research was discouraged by using agricultural research as a means to solve concrete problems faced by the Brazilian farming sector. Pursuing an open innovation system and IPR policy in the agricultural sector facilitated technology transfer, diffusion of new cultivars, and the filing of international patents. An IPR policy that favored social well-being rather than benefiting just corporations allowed new technology to be distributed at production costs only.

These factors may be used as guiding principles for the design of public organizations providing agricultural research and extension services in developing countries. The adequacy of the Embrapa model, however, will depend upon a number of country-specific factors, including the country's development level (and its corresponding technological needs) and the size of its economy, which ultimately defines to what extent such organization is affordable, among other issues (discussed in detail in conclusion of this note). It would be incorrect, therefore, to assume that replicating Embrapa's experience in a different context would necessarily lead to similar results. This note also presents three examples of how Embrapa's technologies and techniques dramatically affected the Brazilian agriculture, and discusses how certain institutional characteristics enabled Embrapa to succeed while other similar organizations did not.

Technology and Productivity in Brazil's Agriculture

This section presents three case studies. The first highlights the transformation of the Cerrado's soil, which opened up a vast amount of comparatively cheap, idle, but potentially arable land, helping to competitively produce agricultural (including livestock) exports for international markets. The other two cases outline the introduction of new soybean and cotton seeds that were adapted to local characteristics of the soil and climate and which raised the land productivity for those crops. Although these cases offer insight for other countries, it would be simplistic to assume that replicating Embrapa's experience in a different context will have the same result.

Turning the Cerrado into an arable land

Brazil's Cerrado covers an area of 2 million square kilometers in the central region of the country, equivalent to approximately 22 percent of the country's total area. It is the second largest biome in Brazil, surpassed only by the Amazon (figure 1). Until the early 1970s, the area was used mainly for low-productivity activities, such as extensive cattle ranching. During this period, Brazilian commercial agriculture, particularly grain crops, was located primarily in the states of Rio Grande do Sul, Parana, and São Paulo. By the late 1970s, however, a rise in land prices in southern states made the cultivation of land-intensive crops such as grains increasingly unviable from a commercial standpoint.[4] Expanding agriculture toward the Cerrado was a natural option for southern farmers, given the availability, land prices, and its overall climate.[5] The problem, however, was the soil, which was extremely poor in nutrients and high in acidity, both of which made it unfit for commercial agriculture.

To reduce the soil's toxicity, Embrapa employed a technique called *agricultural liming,* a process in which industrial quantities of lime are poured onto the soil to reduce acidity levels. In 1990, between 14 million and 16 million metric tons of lime were spread on Brazilian fields. Embrapa also developed varieties of *rhizobium*, a bacterium that helps fix nitrogen in legumes (such as soy), specifically adapted to the Cerrado soil, thereby reducing the need for fertilizers. Embrapa cross-bred an African grass called *brachiaria* with a native Cerrado grass to engineer a variety that produced 20–25 tons of grass feed per hectare, many times the native grass yield and three times the yield in Africa. This allowed parts of the Cerrado to be transformed into high-yielding pasture, helping reduce the average time needed to raise an animal for slaughter from four years to 18–20 months, expanding Brazil's beef herd and the international competitiveness of Brazilian beef exports.[6] Other important technical solutions promoted by Embrapa include promoting soil recuperation, minimum tillage, and crop and cattle integration.

Figure 1. Brazil's Cerrado

Source: IBAMA (Instituto Brasileiro do Meio Ambiente e dos Recursos Naturais Renováveis)

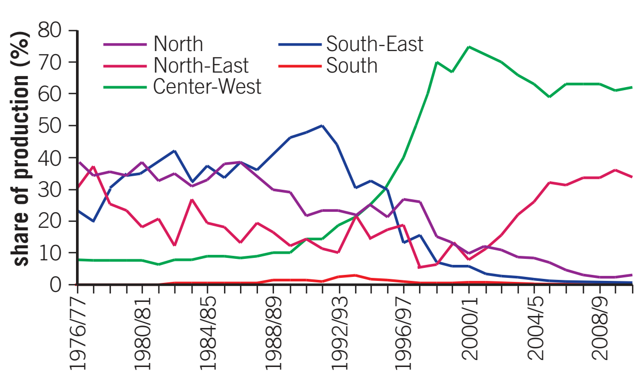
By increasing the fertility of the Cerrado, Embrapa opened up for cultivation one of the largest reserves of arable land in the world. This, in turn, helped keep the price of marginal land down and the cost of Brazilian agricultural exports competitive in international markets. The U.S. Midwest and Argentina still possess the most productive land for temperate climate crops (such as soybeans). But, as the availability of land for agricultural expansion declined in those countries, Brazil's Cerrado became one of the most productive marginal lands worldwide (Rezende 2002). Not surprisingly, about 20 percent of the land in the Cerrado is owned by foreign investors. Figure 2 shows the spectacular increase of the share of the Center-West Region in national agricultural production, going from 10 percent to between 60 and 70 percent in just a decade.

Although new techniques introduced by Embrapa played a major role in the success of agribusiness in that region, other factors also had significant impacts, including (i) good geographic conditions (a topography suited to mechanization and rainfall patterns suitable for summer crops); (ii) improvements in the transportation infrastructure; and (iii) tax incentives.[7]

Biannual harvest of soybeans

The soybean plant is native to the more temperate regions of northeast Asia (Japan, the Korean peninsula, and northeast China). It is a short-day (long-night) crop that is naturally better suited to grow in latitudes above 30 degrees. In Brazil, the production of soybeans in the South Region, where climate conditions are similar to those in temperate regions, picked up in the late 1960s. In the decades that followed, the soybean subsector established itself as a core activity of Brazilian agribusiness. Increases in cultivated area (from 1.3 million to 8.8 million ha) and incremental productivity gains (from 1.14 to 1.73 tons/ha) caused output volumes to grow tenfold

Figure 2. Regional Distribution of Agricultural Production



Source: Compania Nacional de Abstecimento (CONAB).

(from 1.5 million to more than 15 million tons) between 1970 and 1980. In the 1970s, soybean production was concentrated in the southern states. While cheaper farmland made the Center-West Region attractive, the predominantly tropical climate of the region limited the expansion of soybean farming in the Cerrado area.

As a first step, and in addition to introducing general techniques to reduce soil toxicity such as the agricultural liming, Embrapa promoted the development of cultivars with better agronomic adaptation to the tropical climate and more tolerance for the Cerrado's acidic soil. Cross-breeding techniques eventually led to the development of soybean varieties with a lifecycle 8–12 weeks shorter than that of the typical plant. The shortened lifecycle enabled two harvests per year. Embrapa also developed cultivars more resistant to diseases like frogeye, stem canker, mildew, and red root rot, reducing crop losses as well as expenditures on insecticides and contributing to higher yields. The inoculation of soybean seeds with nitrogen-fixing bacteria has almost eliminated the need for nitrogen fertilizers, leading to savings of R$7.5 billion per year, according to Embrapa's estimations (*The Economist* 2010).

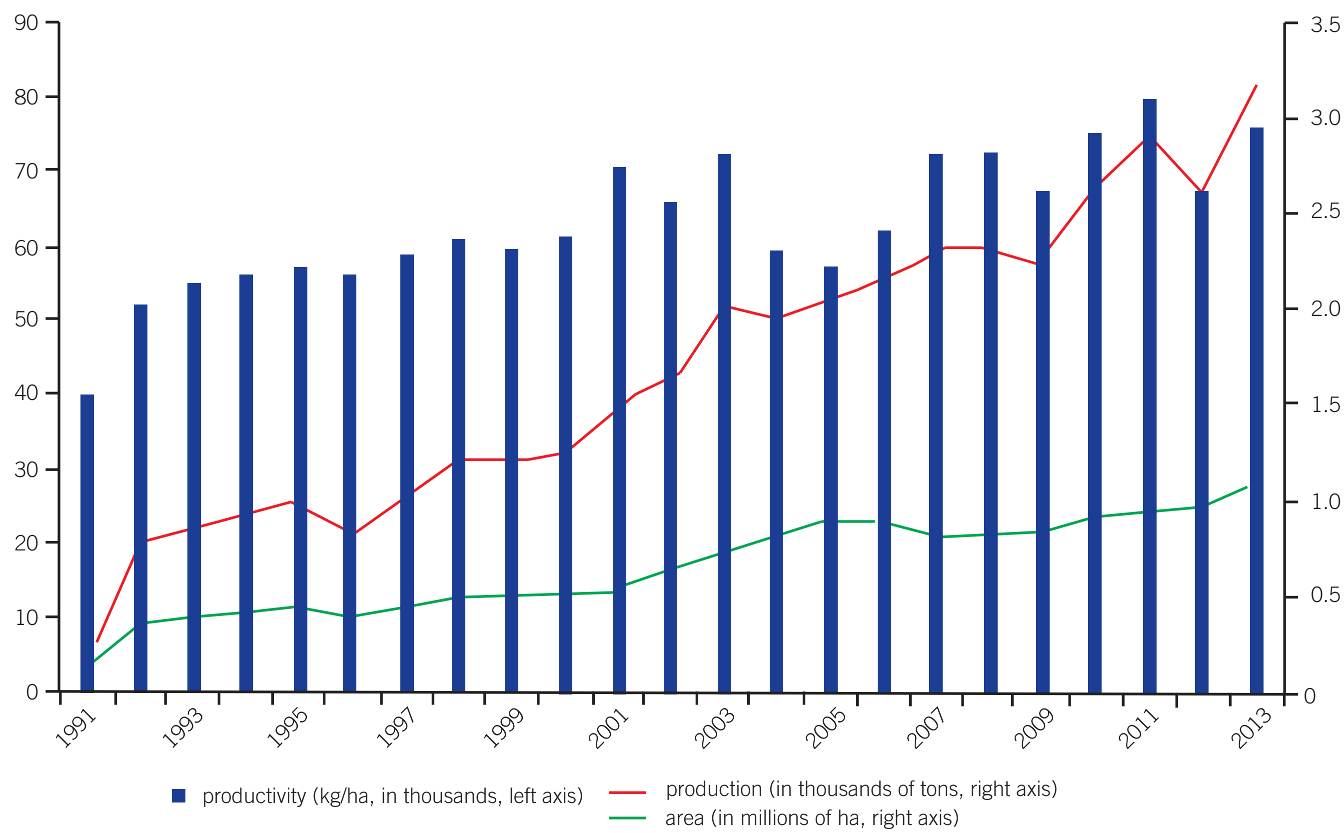
The development of short-photoperiod soybeans and the development of nitrogen-fixing rhizobia were game changers. The discovery of the long juvenile period, which delays flowering under short-day conditions, was the greatest innovation in recent times for the genetic improvement of soybeans in Brazil.[8] The second crop significantly expanded land productivity in the soybean industry, reaching an average of about 2.75 tons/ha in 2006–10 (figure 3). By 2013, more than 70 percent of total soybean production was generated in the Cerrado.

Revival of the cotton industry

Until the mid-1980s, the Brazilian cotton crop, concentrated in the South and South-East regions, was characterized by low productivity. At that time, the emerging boll weevil plague hit the sector hard. Moreover, beginning in 1990, trade liberalization significantly increased import competition. These two events combined with devastating effects: cotton production dropped from nearly 1 million tons in 1981 to 420,000 tons in 1992, while cultivated areas diminished from 4.1 million ha in 1981 to 1.3 million ha in 1995. The cotton crisis had both economic and social impacts, given the importance of the sector for the employment of low-skilled workers. In response, Embrapa started to work on the development and adaptation of cottonseeds in the state of Mato Grosso, the heart of Brazil's Cerrado.

The Cerrado's climate conditions are generally favorable for growing cotton. Temperatures in Mato Grosso remain in a narrow band throughout the year, from 73–82° F (23–28° C). The result is a long growing season, up to 210 days, de-

Figure 3. Soybean Production, Productivity, and Acreage



Source: Compania Nacional de Abstecimento (CONAB).

pending on the timing of monsoonal rains. From October to March, monthly precipitation ranges from four to eight inches, tapering off to virtually zero in July, the peak harvest month. The combination of regular rainfall throughout the growing season and sandy, well-drained soils means that cotton yields in the Cerrado surpass irrigated yields in many parts of the world. The virtual absence of rain during harvest minimizes crop damage, and the well-drained soils mean that fieldwork is seldom impeded by rainfall. One drawback of the climate is the lack of a cold period to help kill off harvest pests. As a result, insecticide expenditures per hectare are among the world's highest.

The development of the CNPA ITA 90 seed increased cotton yields and made the fiber quality equivalent to that of the imported product, beginning the expansion of cotton cultivation in the Cerrado. The first experiments in Chapadão do Parecis were expanded to southern Mato Grosso and received the support of the Mato Grosso Foundation, which went on to encourage the adoption of cotton across the Cerrado in the state. Research was funded by programs such as Facual, Fialgo, Fundeagro, Pluma, and regional cotton quality improvement programs such as PROALMAT, PROALGO, and PROALBA. Figure 4 shows the remarkable turnaround in Brazil's cotton production: by 2010, cotton output had reached precrisis levels, and although the area cultivated remained essentially unchanged, the land yields of 1,500 kg/ha were three times greater. In fact, the productivity of the Brazilian cotton sector became the third highest in the world after Israel and Australia. Most cotton production is currently outside the South and South-East regions, in Mato Grosso and Bahia, which lie within the vast area of the Cerrado. These two states account for more than 90 percent of Brazil's total cotton production (ICAC 2011).

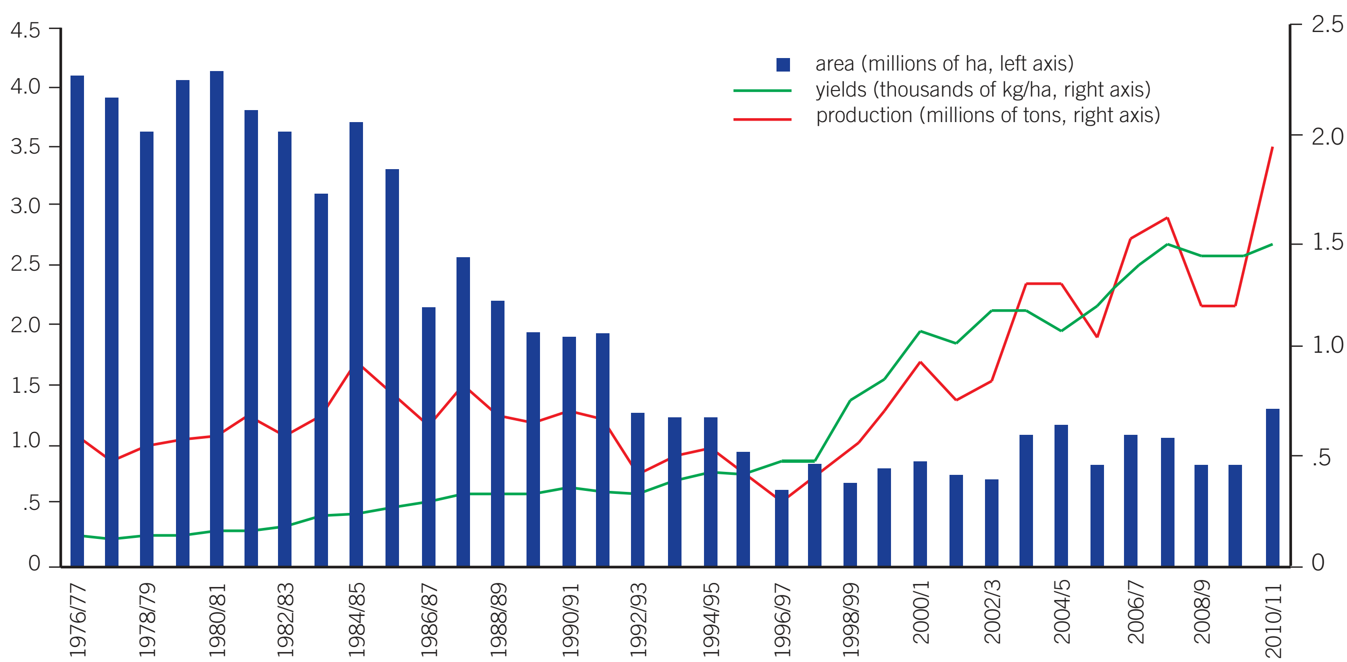
Factors Contributing to Embrapa's Performance: Some Hypotheses

This section explores factors contributing to Embrapa's capacity to effectively develop and transfer new technologies to the Brazilian farming sector to help increase agricultural productivity. Research productivity (the generation of excellent research within a reasonable time and at reasonable costs) and market relevance are common challenges faced by public research organizations like Embrapa. Efficient technology transfer—that is, technology transfer accomplished within a short period of time and at costs affordable to the producers—is another. How did Embrapa address those issues and get it right? Four key factors have contributed to Embrapa's performance: (i) adequate public funding; (ii) sustained investment in human capital; (iii) international collaboration and research excellence; and (iv) mission orientation and IPR policy.

Adequate public funding

The federal government's allocation of the necessary funding for a sufficiently long period was a critical factor to success. Brazil's federal government funds up to 95 percent of Embrapa's total budget.[9] Figure 5a shows the sustained and increasing investment made by the Brazilian government in Embrapa between 1974 and 2008. Particularly striking is the

Figure 4. Output, Area, and Yield of Brazil's Cotton Industry, 1976–2011

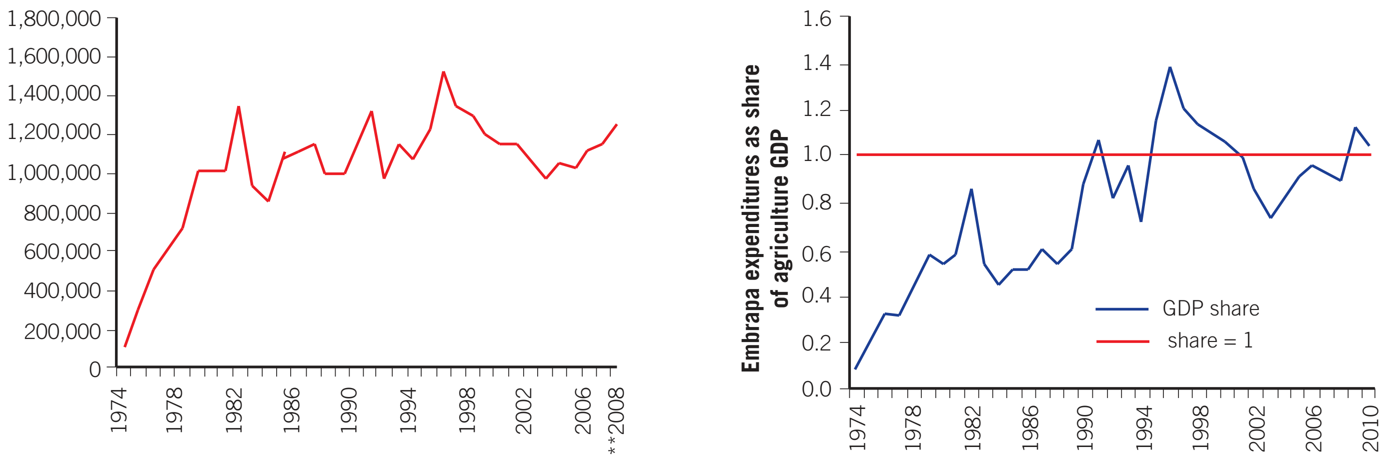


Source: Compania Nacional de Abstecimento (CONAB).

Figure 5. Brazil's Budget

a. In real terms

b. Share of agricultural GDP (values adjusted by IGP-DI)



Source: Embrapa.

rapid growth of Embrapa's expenditures in the nascent stage (1974–82), when important initial investments were needed. A decline occurred from 1997 to 2002, greatly influenced by the macroeconomic adjustments of the Real Plan—the economic stabilization program introduced in Brazil in July 1994 that was successful in bringing inflation down from the extremely high levels that had prevailed.[10] Embrapa's budget cuts were much less severe than those imposed on other public organizations, however, in fact, in a period of macroeconomic imbalances and tight fiscal policies, it is revealing that Embrapa's budget did not falter much. Spending resumed a growing trend in 2003, and the 2008 budget was one of the four biggest during 1974–2008.

Figure 5b illustrates the evolution of Embrapa's budget as a share of agriculture GDP. Expenditures increased from less than 0.2 percent of the agricultural GDP in 1974 to about 1 percent in the 1990s, reaching a peak of 1.4 percent in the mid 1990s. Embrapa's expenditures since 1990, at around 1 percent of agricultural GDP, compare well with figures of public spending on agricultural R&D in more developed countries, such as Canada, the United States, and Australia (1.2 percent, 1.4 percent, and 0.8 percent, respectively, for 2006–9).

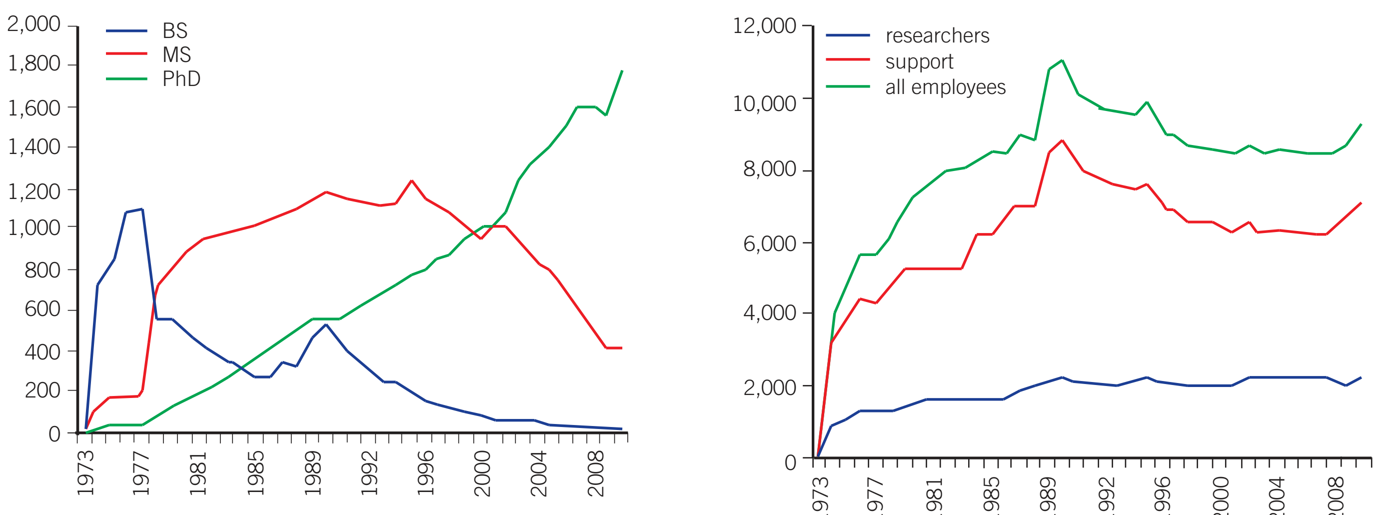
Sustained investment in human capital

Embrapa's human resources policy of aggressively developing the capacity of its researchers is another reason for its success. Figure 6a highlights the gradual increase in the number of professionals with postgraduate qualifications, initially at the master's degree and then at the PhD level. Investments in training between 1974 and 1982 accounted for approximately 20 percent of the budget, totaling US$214.6 million funded via the federal government or international institutions, including the World Bank, the Inter-American Development

Figure 6. Increase in Highly Qualified Researchers

a. Researchers' qualifications

b. Employment: researchers, support staff, and all employees



Source: Embrapa.

Bank, and the Food and Agricultural Organization of the United Nations (see Alves [1984]). Embrapa currently employs over 9,200 people, including more than 2,000 researchers, three-fourths of whom have doctoral degrees.[11] These investments in human capital have helped Embrapa accumulate a critical mass of scientists who have formed a robust research network with diverse talents.

Figure 6b illustrates the steady increase in the number of employees and the proportion of highly qualified researchers at Embrapa. It shows the decline in the number of nonresearch personnel and the stability of the number of researchers in total employment. Embrapa prioritized the retention of research talent by promoting a meritocratic culture, particularly in its recruitment and promotion of researchers. Each research center had clear objectives outlined for the long term, short-term goals, well-defined deadlines, and metrics to measure results. As a company, Embrapa could have a salary structure different from the standard structures of public administration in Brazil, allowing it to reward results by allocating bonuses for high-performance centers. An evaluation system has been in place since 1996 to judge merit, but the incorporation of meritocratic advancement procedures has been difficult, in many cases hampered by cronyism and labor legislation.

International collaboration and research excellence

International collaboration, such as the transfer of research results, the development of joint research projects and training, also played a dynamic role in Embrapa's ability to achieve effective results. Being able to borrow from the international pool of available knowledge was probably a major component of Embrapa's success.

For example, the breeding program for short-photoperiod soybeans benefited from collaboration between Embrapa and USDA-ARS, including from the access to the germplasm[12] of soybeans. Similarly, the International Center for Tropical Agriculture (CIAT) provided the germplasm of forages such as the *bracharia* and *panicum* species. Having access to this pool of knowledge was vital for subsequent adaptation.

Training for researchers in the best foreign universities was a priority for Embrapa in the initial years, when local universities had limited capacity in the fields of agriculture and agricultural research. So Embrapa hired researchers with degrees from foreign universities and sent other researchers abroad for training opportunities, including at leading universities and research organizations in the United States, Europe, Canada, and Australia, among others.[13] This helped build academic relationships around the world and led to the inclusion of Brazilian researchers in relevant research networks.

By 2013, Embrapa had established 78 bilateral agreements with 56 countries and 89 institutions, comprising research partnerships as well as technology transfers.[14] The organization had become a leader in south–south cooperation and conducted technology transfers with markets in Africa (including Ghana, Senegal, Mozambique, and Mali) and the Americas (including the República Bolivariana de Venezuela, Ecuador, Colombia, and Panama). Embrapa also created Virtual Labs Abroad (Labex) as another step toward increasing international collaboration. The United States (USDA-ARS) was the first partner in this project. Subsequently, Labex Europe was created in Montpellier, France, and expanded into other countries including the Netherlands and the United Kingdom.

Mission orientation and IPR policy

From the outset, Embrapa's organizational focus has been on improving agricultural productivity through applied research and technology transfer to farmers. Its creation as a mission-oriented institute dedicated to using agricultural research as a means to solve concrete problems faced by the Brazilian farming sector helped it avoid the temptation of investing in curiosity-driven research and, to some extent, its capture by purely academic interests (Alves 2010). Mission-orientation led to the creation of National Product Programs, which were very effective at identifying the needs of specific crops and directing resources toward the development of technological solutions.

Embrapa was also conceived as a broad network of research entities, each specializing in a particular topic, with decentralized control over decision making. The agency's decentralized model of applied research split it among national commodity, regional resource, and "thematic" centers, enabling both a national and local focus. Close connection with the farming sector and a solid feedback system helped focus activities on the final goal of improving agriculture productivity (rather than generating academic publications) through technology transfer. As of December 2013, Embrapa had a presence in almost all 27 states in Brazil. It has 38 research centers, three service centers, and 13 central divisions.[15] Its widespread presence facilitates a working relationship between farmers and the researchers who want to understand their needs. Farmers know, for example, that the unit responsible for maize research is the National Research Center for Maize and Sorghum, located in Sete Lagoas–Minas Gerais.

Another benefit from mission orientation was the efficiency through which scientific output was transformed into proof of concepts: prototypes and innovation. This transition is a common challenge in research commercialization. Researchers in public research institutes and universities are often reluctant to engage in commercialization efforts that may reduce the time available for the development of other research. Embrapa's mission orientation merged these two separated activities into one continuous task. Prototypes were evaluated on Embrapa's testing farms or in collaboration with similar organizations, including from the private sector. In fact, Embrapa realized that close cooperation with other institutions in research and commercialization was pivotal to success, and, depending on the complexity of the productivity challenge, Embrapa either produced new varieties by itself or entered into production agreements with select private and public partners.[16]

Lastly, the open innovation system and IPR policy adopted by Embrapa, coupled with a network of extension services, enabled an effective diffusion of research results. While Embrapa has adopted a flexible approach to IPR throughout its history—with some emphasis on patenting and licensing in recent years—the distribution of improved seeds at minimum costs followed somewhat naturally from its original mandate, that is, improving agricultural productivity. In cases of research organizations with a research mandate only, one must wonder whether some results simply end up idle on labs' shelves. Monopoly pricing—the natural strategy of a private research company—would, by definition, restrain access to research results by producers. By placing farmer's profitability at the center of its objective function (to the detriment of its own financial gains), Embrapa maximized economic returns to public investments in R&D—as measured by the widespread productivity gains in agriculture, plus spillovers in terms of stronger export performance and geographic decentralization of growth.

Conclusions

Embrapa grew out of one of a handful of technology policies that enabled the development of potentially profitable activities in developing economies, similar to the wine industry in Chile, the exportation of palm oil in Malaysia, and the production of cut flowers in Kenya (Chandra 2006). There is, however, one major difference: the scope of agricultural activities covered by Embrapa is considerably larger. Since its founding in 1973, Embrapa has created and transferred to Brazilian farmers more than 9,000 technologies and built an intellectual property portfolio of more than 350 cultivars and about 200 international patents. It is currently considered the world's leading tropical research institute.

Embrapa generated and transferred new technologies and techniques tailored to Brazil's climate and soil conditions. The use of these technologies by Brazilian farmers facilitated the expansion of Brazilian agriculture and increased exports at internationally competitive prices—first, by expanding the supply of arable land, and, second, by improving the productivity of selected crops. New techniques to improve the quality of the otherwise inhospitable Cerrado soil opened a vast tract of newly arable land, keeping marginal agricultural costs down and enabling an increase in agricultural production, while improvements in the cultivars of soybeans and cotton ultimately yielded biannual harvests. Both activities increased the productivity of land.

Why did Embrapa succeed where other research organizations failed?

Embrapa's mission orientation, focusing from the outset on the improvement of agricultural productivity rather than the production of scientific work, was a key driver of its success. Integration into the international flow of knowledge increased research efficiency and accelerated training. An open IPR policy—and a network of offices spread throughout the country—facilitated the dissemination of Embrapa's discoveries. Funding was kept at adequate levels for more than two decades. Investments in human capital were highly prioritized. A meritocratic culture has been actively promoted by the organization. As a result, research dealt with the practical problems of agriculture, while technology and innovations sourced through Embrapa were quickly deployed by farmers. By reacting to market signals and focusing on activities for which demand was increasing in international markets, Embrapa avoided the usual challenges of purely "supply-push" technology transfer policies.

Is this experience replicable?

Embrapa's institutional arrangements and policies—operational independence, sustained public investment in mission-oriented research, investment in human capital, and integration into international flow of knowledge—are certainly replicable across a variety of policy environments. Setting up a public research organization with a similar structure will require policy and continued financial support as well as a focus on tangible, practical results. The customization aspect of Embrapa's operations, with researchers focusing on technologies that address specific challenges, requires some form of decentralization to establish close contacts with farmers. However, there are important caveats to keep in mind:

(i) As indicated by the increase in land area used for crops and livestock preceding the creation of Embrapa, R&D and technology policy *aimed to address bottlenecks to the development of existing comparative advantages in Brazil* and avoiding the common challenge of promoting activities not consistent with the country's factor endowments.

(ii) While critical for the enhancement of agricultural productivity, agricultural research and extension services were part of *a broader set of policies and institutional development* that positively affected agricultural productivity (from rural credit to trade liberalization).

- The search for new techniques to improve the Cerrado's soil was in response to the rising price of arable land in the South Region of Brazil in the 1980s. Without a functioning market for arable land, price signals would not exist. The migration of farmers from the south brought preexisting agricultural knowledge to the Central-West Region, particularly with respect to crops such as soybeans, as well as perhaps decades of *entrepreneurial experience* in agribusiness.

(iii) Brazil had and has the *necessary critical mass and commensurate public funding prowess*, which permitted investments of the required scale and time horizon. This is not the case for many smaller developing countries (for example, in Central America) where other collaborative research approaches (for example, the Consultative Group on International Agricultural Research [CGIAR] model) may be more appropriate.

(iv) Embrapa filled a gap when public investments in science and technology were essential for the development of a modern commercial agriculture. As agricultural needs change and other players are present 40 years down the road—such as universities and the private sector—the Embrapa model will need to be revised.

(v) In this sense, it is important to bear in mind that the factors of success identified here refer to a past period (roughly 1974–2004), and they do not necessarily reflect the policy and institutional choices of Embrapa at present.

Acknowledgments

The paper upon which this note was drawn was funded by the 2013 LAC-Innovation Beam and prepared in May–June 2013 under the supervision of Esperanza Lasagabaster and Marialisa Motta. The authors wish to thank Braz Henrique Nunes Rodrigues, Cláudio Takao Karia, Domingo Heroldo, Rudolfo C. Rinhardt, Eduardo Riedel, Filipe Geraldo de Moraes Teixeira, Felipe Teixeira, Gervasio Castro de Rezende, José Renato Faria, Paulo Roberto Galerani, José Roberto Rodrigues Peres, and Marcos Esteves for their valuable inputs to the paper. Special gratitude goes to Eliseu Roberto de Andrade Alves and José Roberto Mendonça de Barros for their valuable collaboration and insights. The authors are also grateful to Gregory V. Wolf, Erick Fernandes, Mark Dutz, Mark Roland Thomas, Otaviano Canuto, Willem Janssen, and two anonymous reviewers for the comments to previous drafts of this paper. Morten Seja provided research assistance.

About the Authors

Paulo Correa is a *Lead Economist* at the *Innovation Technology and Entrepreneurship Unit* of the *Finance and Private Sector Development Global Practice* of the *World Bank*. *Cristiane Alkmin Junqueira Schmidt* has a *PhD in economics* from the *EPGE-FG* (Rio de Janeiro, Brazil) and currently teaches in the MBA programs of *FGV*. *Schmidt* was also a *Visiting Scholar* at *Columbia University*.

Notes

1. Cultivars are new seeds with improved performance due to better adaption to specific clime and soil (edaphoclimatic) conditions.

2. In terms of farm size and efficiency, Helfand and Levine (2004) find a U-shaped curve with decreasing efficiency up to about 500 ha and then increasing efficiency up to 10,000–20,000 ha.

3. Rada and Valdes (2012), for example, estimate that each 1 percent increase in Embrapa's cumulative research investment raises the productivity of the most efficient farms by 0.2 percent. For large farms that were able to seize economies of scale, the productivity improvements are estimated to be particularly pronounced.

4. For instance, by 1977–79, the price of a hectare of arable land in the states of Rio Grande do Sul and Parana was about three and six times higher, respectively, than in Mato Grosso (see Rezende [2002]).

5. The climate conditions are especially suitable for cotton; the steady temperature allows for a longer growing season, the topography is suited to mechanization, and rainfall patterns are suitable for summer crops.

6. The Cerrado had low-yielding varieties of native grass that lowered the productivity of cattle rearing. Embrapa has recently begun experiments to modify *brachiaria* genetically to produce a larger-leafed variety called braquiarão, which promises even bigger increases in yields.

7. Examples of government programs to attract migrants from other regions included the Program Directed Settlement of Upper Paranaíba (PADAP), the Development Program of the Cerrado (POLOCENTRO), and the Program for Japanese–Brazilian Cooperation for Development of the Cerrado (PRODECER).

8. Embrapa has produced the largest worldwide program of soybean improvement in the tropics by developing cultivars with higher juvenile periods.

9. International organizations, such as the Food and Agriculture Organization of the United Nations, the World Bank Group, and the Inter-American Development Bank contributed regularly to the budget. However, since the initiation of Embrapa, the vast majority of its budget derives from government funding. For example, the PRODETAB project that was cofinanced by the World Bank contributed around 1 percent of the agricultural R&D expenditure in Brazil (see Pardey, Alston, and Piggott [2006, 276].

10. Inflation rates of over 50 percent per month fell to approximately 20 percent annually.

11. In comparison, less than 20 percent of the more than 2,300 researchers of the main Argentine agricultural research branch, INTA, hold a PhD.

12. A germplasm is a collection of genetic resources for an organism.
13. After the 1990s, Embrapa started postdoctoral programs through Brazilian universities, which provided training at an international standard. Embrapa now develops its own highly trained professionals through permanent cooperation with universities, research institutes, and overseas research entities.
14. For example, in the United States, Embrapa has relationships with several major universities and the Agricultural Research Service of the U.S. Department of Agriculture; in France, with the INRA, CIRAD, and IRD; and, in Japan, with JICA and JIRCAS.
15. Embrapa has also been coordinating the National Agricultural Research System (SNPA), which includes public and private entities involved in agricultural research in Brazil.
16. Brazilian Innovation Law (federal law 10973, of 2004), article 9º.

References

Alves, Eliseu Roberto de Andrade. 1984. "Brazil's Program for Development of Agricultural Researchers." *Brazilian Agriculture and Agricultural Research* 9 (7): 161–73.

Alves, E. R. A. 2010. "Embrapa: um caso bem-sucedido de inovação institucional." *Revista de política agrícola* 19: 65–73.

Bonelli, R. 2002. "Impactos econômicos e sociais de longo prazo da expansão agropecuária no Brasil: revolução invisível e inclusão social." In *Anais do seminário sobre os impactos da mudança tecnológica do setor agropecuário na economia brasileira*. EMBRAPA Secretaria de Administração Estratégica, Brasília, 241p. (Documentos, n. 5).

Brazilian Agricultural Research Corporation (Embrapa). http://www.embrapa.br/english/embrapa/.

Chandra, Vandana. 2006. *Technology, Adaptation and Exports: How Some Developing Countries Got It Right*. Washington, DC: World Bank.

Evenson, R. E., and Denisard Alves. 1998. "Technology, Climate Change, Productivity and Land Use in Brazilian Agriculture." *Planejamento e politicas publicas* 18: 223–60.

Helfand, Steven, and Edward Levine. 2004. "Farm Size and the Determinants of Productive Efficiency in the Brazilian Center-West." *Agricultural Economics* 31 (2–3): 241–49.

ICAC (International Cotton Advisory Committee). 2011. "The Cost of Raw Cotton Production." In *Brazil's Cotton Industry Economic: Reform and Development*, ed. J. Kiawu, C. Valdes, and S. MacDonald. USDA.

Kouadio, Théodore. 2012. "Africa and Brazil to Share Cotton Know-How." Summary posted by Meridian. http://www.merid.org/en/Content/News_Services/Food_Security_and_AgBiotech_News/Articles/2012/Sep/10/Brazil.aspx.

Pardey, Philip G., Julian M. Alston, and Roley R. Piggott. 2006. *Agricultural R&D in the Developing World: Too Little, Too Late?* Washington, DC: International Food Policy Research Institute.

Portal Brasil. 2010. Research Units: Brazilian Agricultural Research Corporation (Embrapa). http://www.brasil.gov.br/sobre/science-and-technology/research-units/brazilian-agricultural-research-corporation-embrapa/br_model1?set_language=en.

Rada, Nicholas, and Constanza Valdes. 2012. "Policy Technology and Efficiency in Brazilian Agriculture." USDA Economic Research Report No. 137.

Rezende, G. C. 2002. "Ocupação agrícola e estrutura agrária no cerrado: o papel do preço da terra, dos recursos naturais e da tecnologia." IPEA, Texto Para Discussao No. 913, Rio de Janeiro.

The Economist. 2010. "The Miracle of the Cerrado." http://www.economist.com/node/16886442.

The Economist. 2011. "No Easy Fix." http://www.economist.com/node/18200678.

The *Economic Premise* note series is intended to summarize good practices and key policy findings on topics related to economic policy. They are produced by the Poverty Reduction and Economic Management (PREM) Network Vice-Presidency of the World Bank. The views expressed here are those of the authors and do not necessarily reflect those of the World Bank. The notes are available at: www.worldbank.org/economicpremise.